# Information Technology Office Overview

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# DARPA Has Done Great Things for IT

**Mission of ITO: Superiority of Armed Forces Through Revolutionary Advances in:**

- High Performance Computing and Communications Devices
- Networking and Information Assurance
- Embedded Software
- Seamless User Interfaces for the War Fighter
- Ubiquitous Computing and Communication Resources

The investment by DARPA in Information Technology development has been the primary factor in the creation of an information based economy whose current annual volume is about $500 B *per year* in the US alone. This number is to be compared with other sectors of the economy such as communications $1 trillion, transportation $750 B, and health care $2.5 trillion.

That's great: what remains to be done? Where do we go from here?

# Drivers of IT Research

**Computing, Networking, Security have come a long way, but they have a long way to go.**

*Key drivers:*

- wireless and power aware computing devices,
- ubiquitous computing devices,
- embedded computers, (interacting in real time with sensors and actuators),
- wideband optical networks,
- MEMS,
- quantum devices,
- system on a chip: billion transistor chip, photonic interconnects, programmable hardware,
- cognitive neurophysiology,
- bio-informatics.

# What Are the Hard Problems??

## Wireless:

1. Power/ Energy Aware Computing and Communication (PAC/C): design suites for trading off power/energy consumption. Design environments for integrated design across algorithms, instruction sets, and device clock/frequency characteristics.

2. Distributed Computation with sensors which have to trade off on board computation with communication. Thresholding phenomena in performance improvement of networked sensing systems. (SensIT)

3. Secure Ad-hoc networking protocols for insecure and jammable networks. Game theoretical approaches to information assurance in a hostile environment, physical layer and network layer.

# What Are the Hard Problems??

**Ubiquitous Computing Devices:**

1. Hands off interaction with portable or omnipresent computers. Need for voice / speech / foreign language recognition. (Communicator, TIDES)

2. Operating Systems for small sensors, embedded devices for specialized operation. (Ubiquitous Computing)

3. Ad-hoc networking, content addressable data, queries for intermittently available data stores. (Ubiquitous Computing)

4. Dynamic caching of data, data provisioning systems, aggregation of temporally evolving data. (IM, Ubiquitous Computing)

5. Collaborative and Hierarchical Decision Making Environments. (Ubiquitous Computing)

# Hard Problems Continued

## Optical Networking

- WDM is nearing maturity, however optical networking protocols for WDM over IP are not ready yet: routing, congestion control, network management. (NGI)
- Security of high speed networks.
- Modeling, estimation and control of traffic at various levels of granularity on WDM networks, ATM networks, WAN and Ad-hoc Wireless Networks is in its infancy. QoS for different streams of traffic. (NMS)

## MEMS

- Smart matter: the integration of MEMS actuators and sensors with computation and networks. (seedling, amorphous computation)
- SmartDust: usage of MEMS sensors with wireless, GPS, biochemical sensors and ad-hoc networking to enable distributed detection and tracking of bio-hazards (SensIT)
- Computational infrastructure for distributed, Networked Embedded Systems.

# Hard Problems Continued

## Computational Models "Beyond Si"

- New paradigms for secure communication and computation.
- Quantum, DNA, smart matter models of computation: Amorphous Computing. Challenge problems: quantum and string theoretic simulations of molecules.
- Integrate adaptively computational elements ASICs, FPGAs, programmable elements using optical interconnects to incorporate security into computational fabric.
- Programmable hardware with verified components for morphing computational elements and power aware applications. (Just-in-Time, DIS)

# Hard Problems Continued

## Cognitive Neurophysiology:

- Interfacing computer memory to human memory, models of memory and forgetfulness to augment situation awareness. (ISAT Study Area)
- Learning of information search patterns and language acquisition. (TIDES)
- Synthesis of speech, gaze, gesture, and lip reading for noisy, multi-speaker environments.

## Computational Biology:

- Hidden Markov models for biological models of gene expression and phenotype expression. Putting biological content into phenomenological models, bio-informatics.
- Architectures for computation, hardware and software with the fault-tolerant and self-organizational character of biological systems.
- Modeling and Control of genetic circuits for applications like suppression of piliation or forced sporulation, multi-grained models of the organism, cell, DNA, gene computational elements.

# Hard Problems Continued

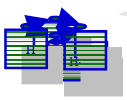
## Embedded Computers and Software:

- Distributed software each performing time critical tasks needed to coordinate with guarantees of overall QoS. (Quorum)
- Verified software for adaptable, time critical operations with multiple distributed processes for physical systems whose mode changes depending on mission priorities. (SEC)
- Model based design of embedded software for hardware-software codesign. The goal is to have embedded software keep up with Moore's law advances in processor speed. (MoBIES)
- Networked Embedded Systems compositionality and distribution of the subsystems is unknown resulting in large cost overruns and worse inadequate performance in real-time embedded software for distributed sensing and control.

# Current ITO Programs

**Intelligent Software**

- Communicator
- Information Management
- Translingual (TIDES)



**Autonomous and Embedded Systems**

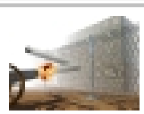
- Autonomous Negotiation Targets (ANTS)
- Mobile Autonomous Robot Software (MARS)
- Software Enabled Control (SEC)
- Model-Based Integration of Embedded Software (MoBIES)
- Software for Distributed Robotics (SDR)
- Program Composition for Embedded Systems (PCES)

**Networking & Distributed Systems**

- Active Networks
- Next Generation Internet (NGI)
- Quorum
- Sensor Information Technology (SensIT)
- Network Modeling and Simulation (NMS)

**High Performance Computing Components**

- Data Intensive Systems
- PAC/C



**Information Survivability**

- Tolerant Networks
- Dynamic Coalitions

**Ubiquitous Computing**

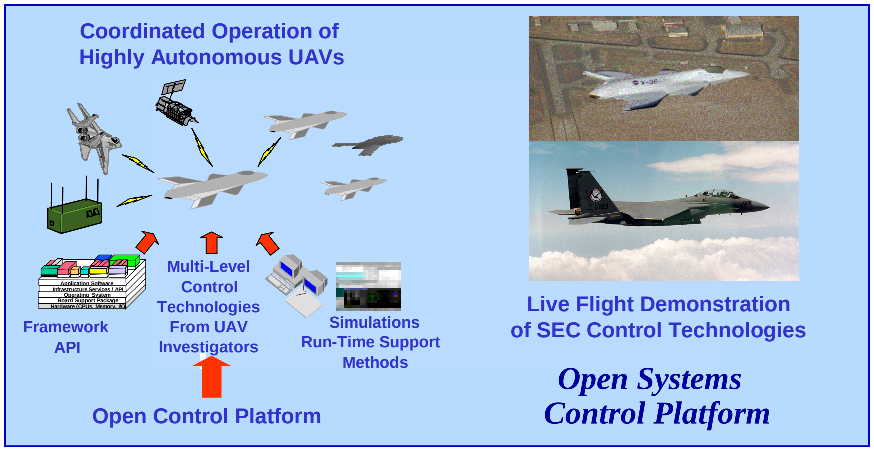
**Seedlings**

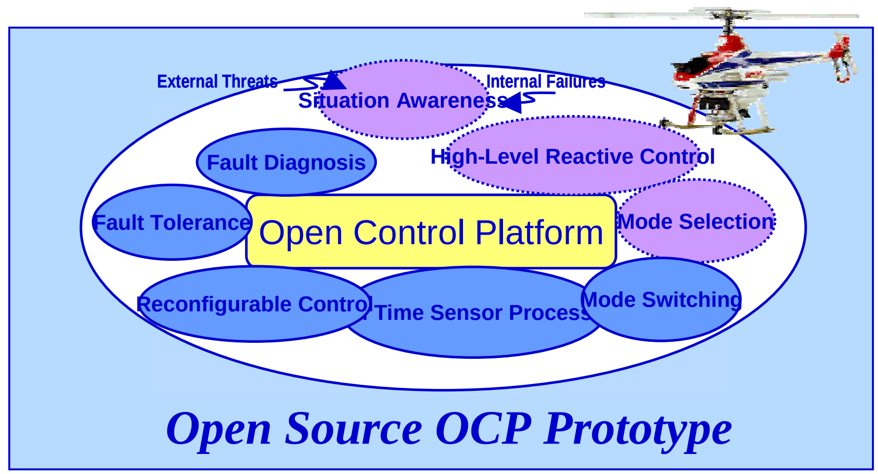
# *Representative Program*

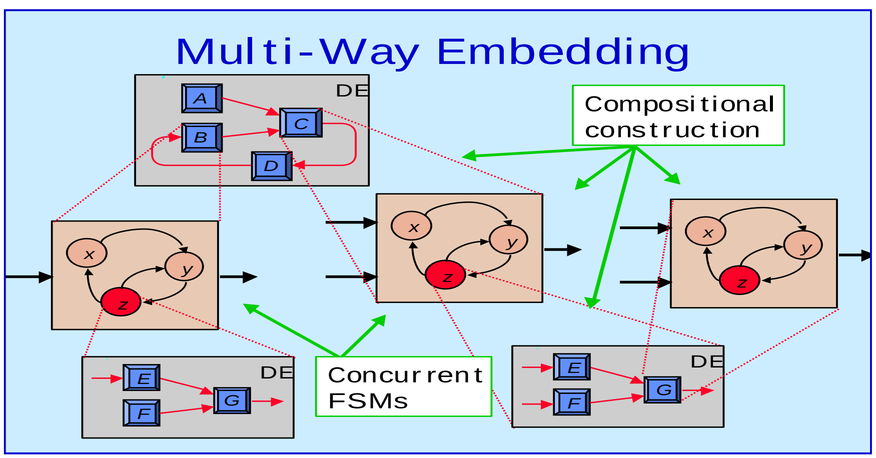
# Software Enabled Control (SEC)

## Technology Goals:

- Control systems that we haven't been able to control before
- Increase automation for extreme maneuvers, tightly coordinated actions
- **Middleware for embedded control systems**



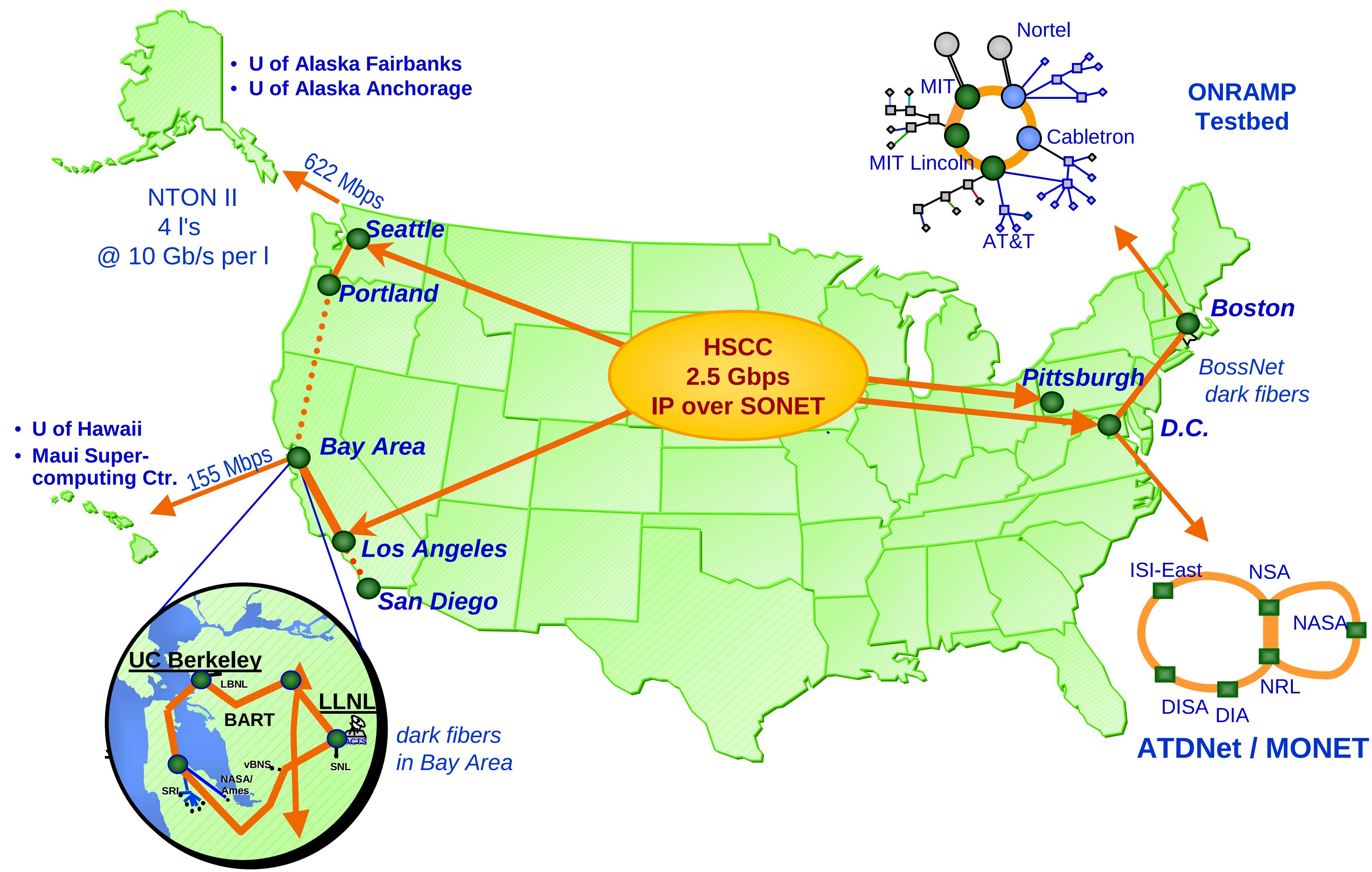




## Coordinated Multi-Modal Control:

- **Control middleware (reusable)**
- Open systems, open source
- Reconfigurable hybrid (discrete and continuous) control loops
- Real-time data services for active (predictive) state models

# SuperNet Testbed
## (www.ngi-supernet.org)



# DARPA's NGI Program Components

- **SuperNet Technology**

  To enable ultra-high bandwidth on demand over national networks guaranteed over the shared infrastructure
  - Simplified protocol layering - IP over dynamic optical network
  - End-to-end performance
  - Testbed

- **Network Monitoring & Management**

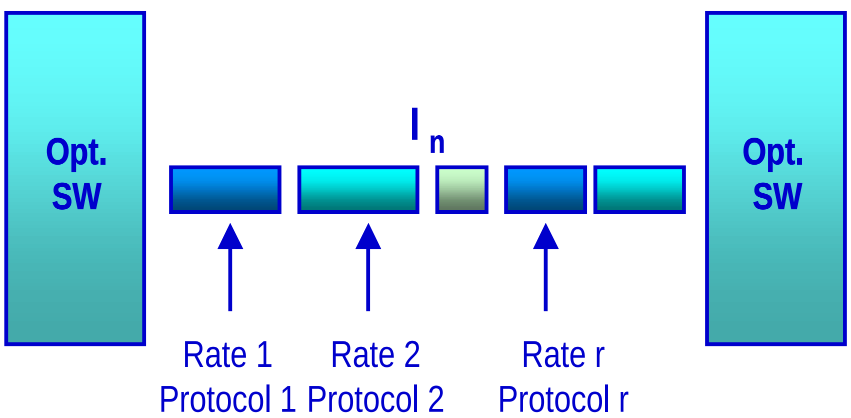
  Create tools that greatly automate planning and management functions enabling networks to grow while limiting the cost and complexity of network management and control
  - Adaptive network management and control software
  - Large-scale network monitoring/analysis/visualization tools

- **Applications**

  Develop, test, deploy applications requiring gigabit end-to-end throughput

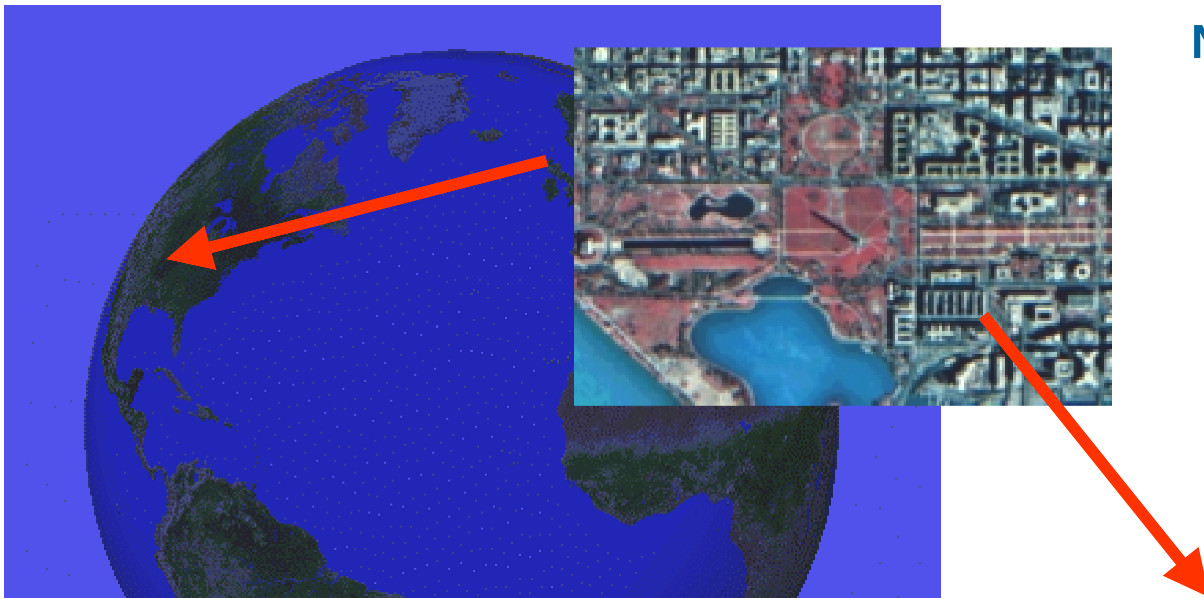
# NGI Experiment: Dynamic Optical Switching

| | holding time | switching speed |
|---|---|---|
| Reconfigurable Opt. Networking | days, months | 50 msec - secs |
| Optical Flow Switching | >100 msec | ~msec |
| Optical Burst Switching | >10 msec ~ 1 msec | ~msec |
| Optical Packet Switching | > msec | ~ nsec |
| All-Optical Switching | > nsec | ~ psec |




Goal: Bit rate and protocol agile

# Surveillance Applications

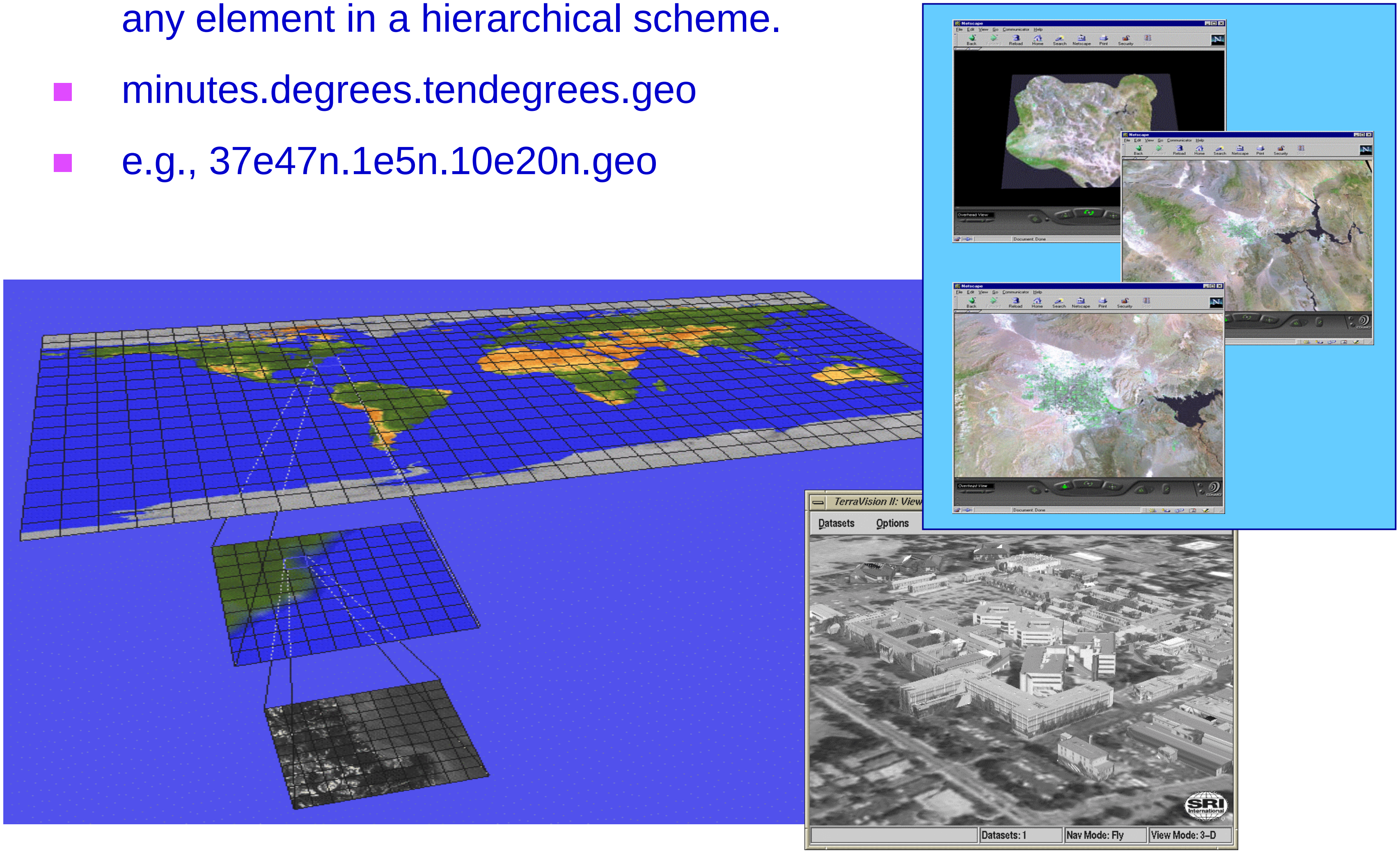


### Networks Supporting

- distribution of multi-resolution representation of the globe and
- telepresence through video / sensor synthesis

# Infrastructure: .geo domain

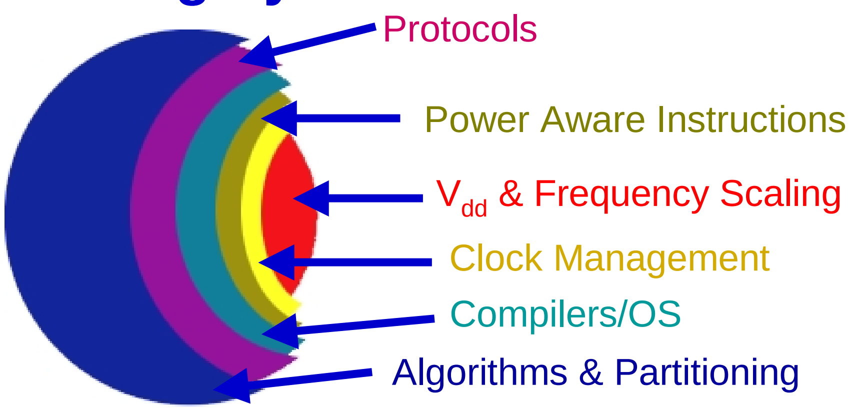
- Use DNS to encode latitude / longitude for any element in a hierarchical scheme.
- minutes.degrees.tendegrees.geo
- e.g., 37e47n.1e5n.10e20n.geo



# Signal Processing & Power Aware Computing/Communication

- **Provide an integrated software / hardware technology suite with the potential to reduce power requirements by 100X - 1000X in (energy * delay) or performance / watt when compared to technology using conventional approaches**

- **Maximize energy conservation at each level while providing intelligent power aware management and optimization of energy and energy distribution at all levels of highly constrained embedded systems**



*Representative Program*

# PAC/C - Enabling Technology


- **Power Aware technologies are critical across a broad range of applications.**
- **Broad cross section of low level technologies required**
- **Provide a technology suite for use by each end user**

**Optimize performance, energy, power demands against instantaneous mission requirements**

*Representative Program*

# Fault Tolerant Networks

***Goal: Ensure continued availability of the network in the face of an attack while containing the resources available to the attacker***

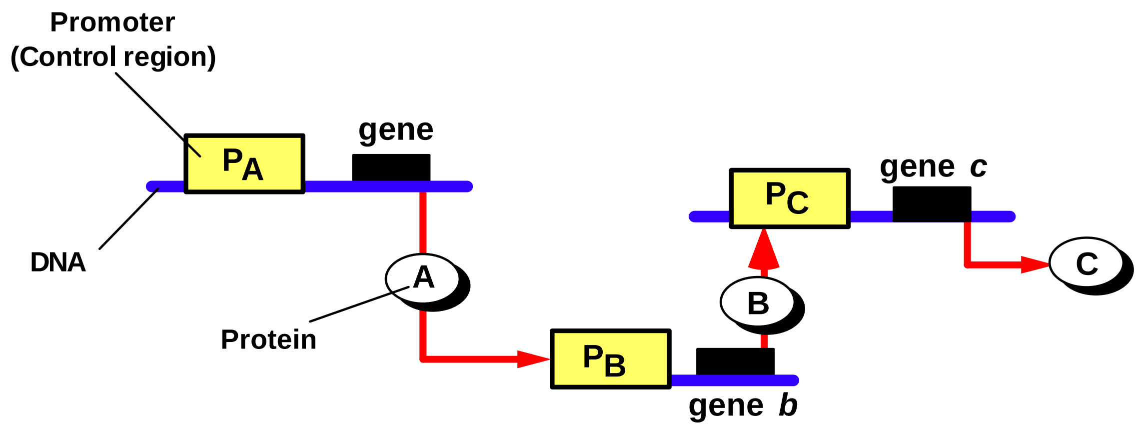
- **Fault-Tolerant Survivability**
  - Apply fault tolerance techniques to networking protocols
  - Better understanding of network fault modeling
  - Explore network overlays as survivability mechanism
- **Denying Denial-of-Service**
  - Allocation methods to constrain attacker's resource use
  - Progress-based protocols link allocation to level of trust
- **Active Network Response**
  - Exploit active networks for traceback
  - Attacker fencing

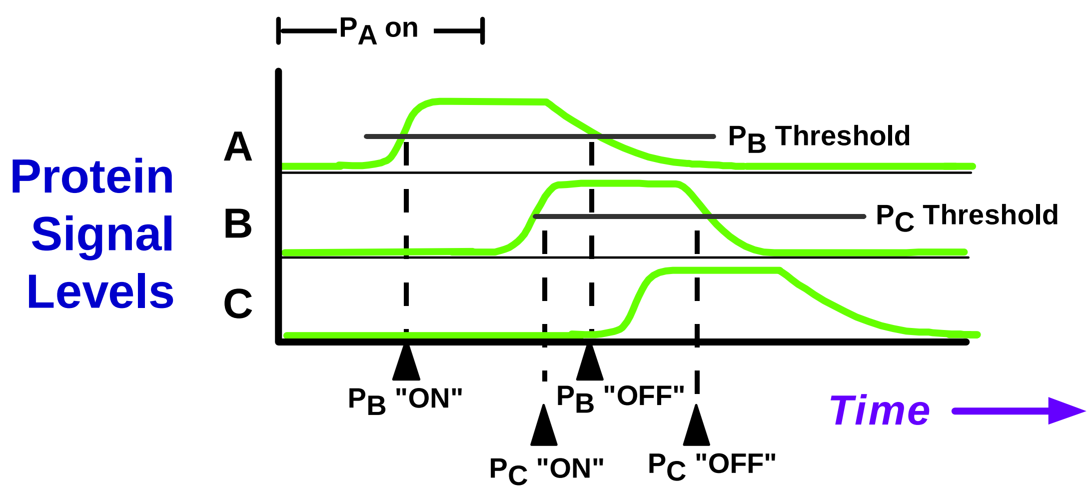
# Bio-Futures
# Computation in Bio-Substrate

- **Hybrid Circuit Models for Biological Information Processing (Bio-Spice)**
  - Hybrid stochastic - deterministic systems
  - Gene regulation control models to predict intervention in pathogens,
  - Design optimal micro-organisms for bioreactors, biomass energy harvesting
- **DNA Computation & Devices**
  - Controlled DNA computing on substrates
    - SAT problems; bio-chips for multi-agent detection
    - Algorithmic self-assembly: sheets, cages (crystallography, molecular electronics)
  - Gates and integrated logic from DNA gene control circuits
  - Memory, databases.
- **Cellular Control systems**
  - Integrated cellular control combining
    - Sensing (aptamers)
    - Actuation (DNA lattice registers, biomotors, production of target biomolecules)
    - Local distributed control
  - Demonstrate control of physiology of normal and pathological cells
    - Sense state of cell
    - Engage gene control networks
    - Produce regulating gene products to switch cell state

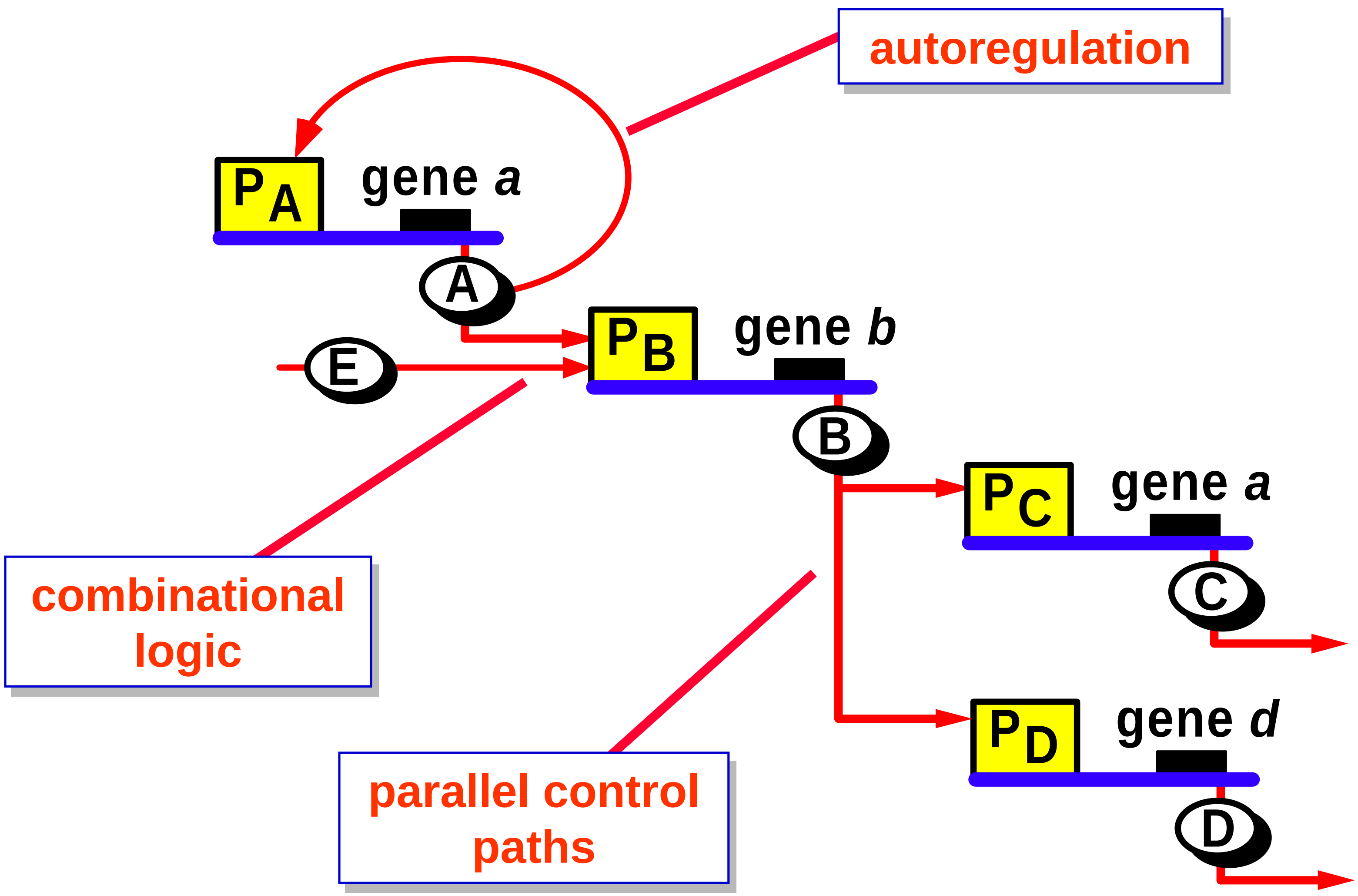
# Protein Concentrations Control Genetic Logic…

## Genetic logic cascade



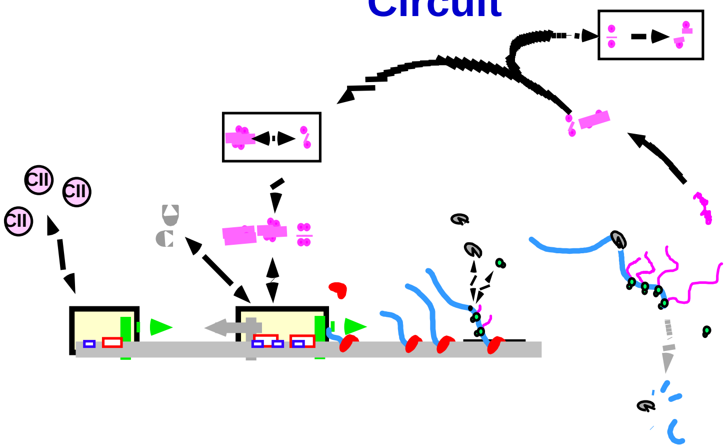



# Complex Regulatory Pathways are Possible . . . .

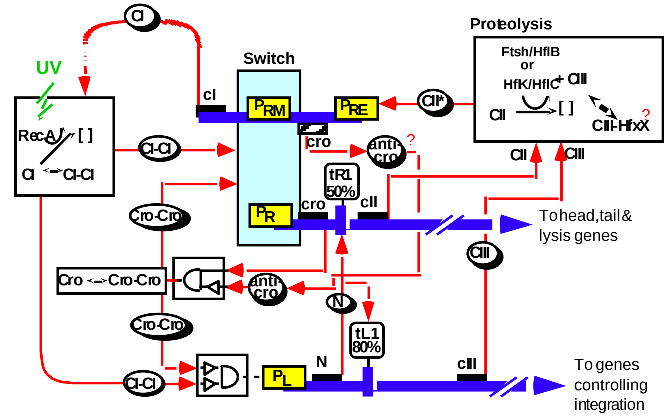


# Modeling and Simulation Approach

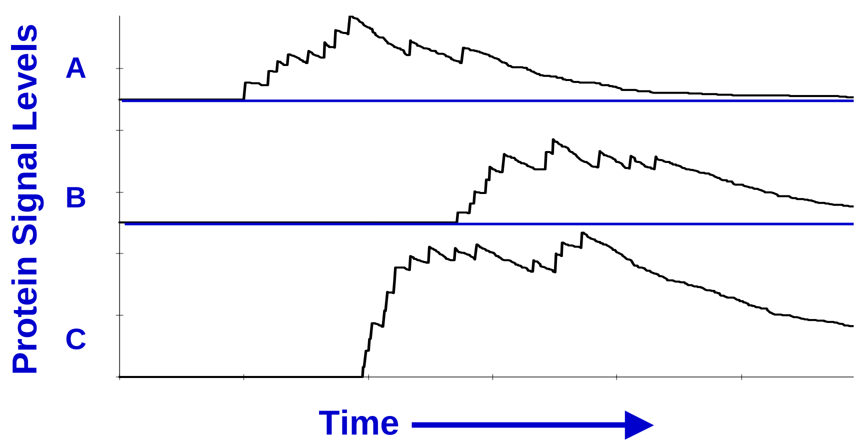
## Molecular Components of Genetic Feedback Circuit




## Genetic Circuit Representation




## Stochastic Mechanisms Produce Fluctuating Signal Levels



# Gene Regulation Networks

## Science & Technology

- Develop tools for characterizing the fundamental architecture and design features underlying the dynamic behavior of genetic regulatory networks

## Technology Needs

- Computer aided design tools for rational design and manipulation of metabolic systems and products
- Broad DOD payoffs
  - Rational Rx for CB and toxic agents
  - New concepts & distributed sensing and control